US 20130199238A1

(19) **United States**

(12) **Patent Application Publication**

**MOCK et al.**

(10) **Pub. No.: US 2013/0199238 A1**

(43) **Pub. Date: Aug. 8, 2013**

(54) **LIQUEFIED NATURAL GAS PLANT WITH ETHYLENE INDEPENDENT HEAVIES RECOVERY SYSTEM**

(75) Inventors: **Jon M. MOCK**, Houston, TX (US); **Megan V. EVANS**, Houston, TX (US); **Attilio J. PRADERIO**, Humble, TX (US)

(73) Assignee: **CONOCOPHILLIPS COMPANY**, Houston, TX (US)

(21) Appl. No.: **13/570,690**

(22) Filed: **Aug. 9, 2012**

**Related U.S. Application Data**

(60) Provisional application No. 61/522,049, filed on Aug. 10, 2011.

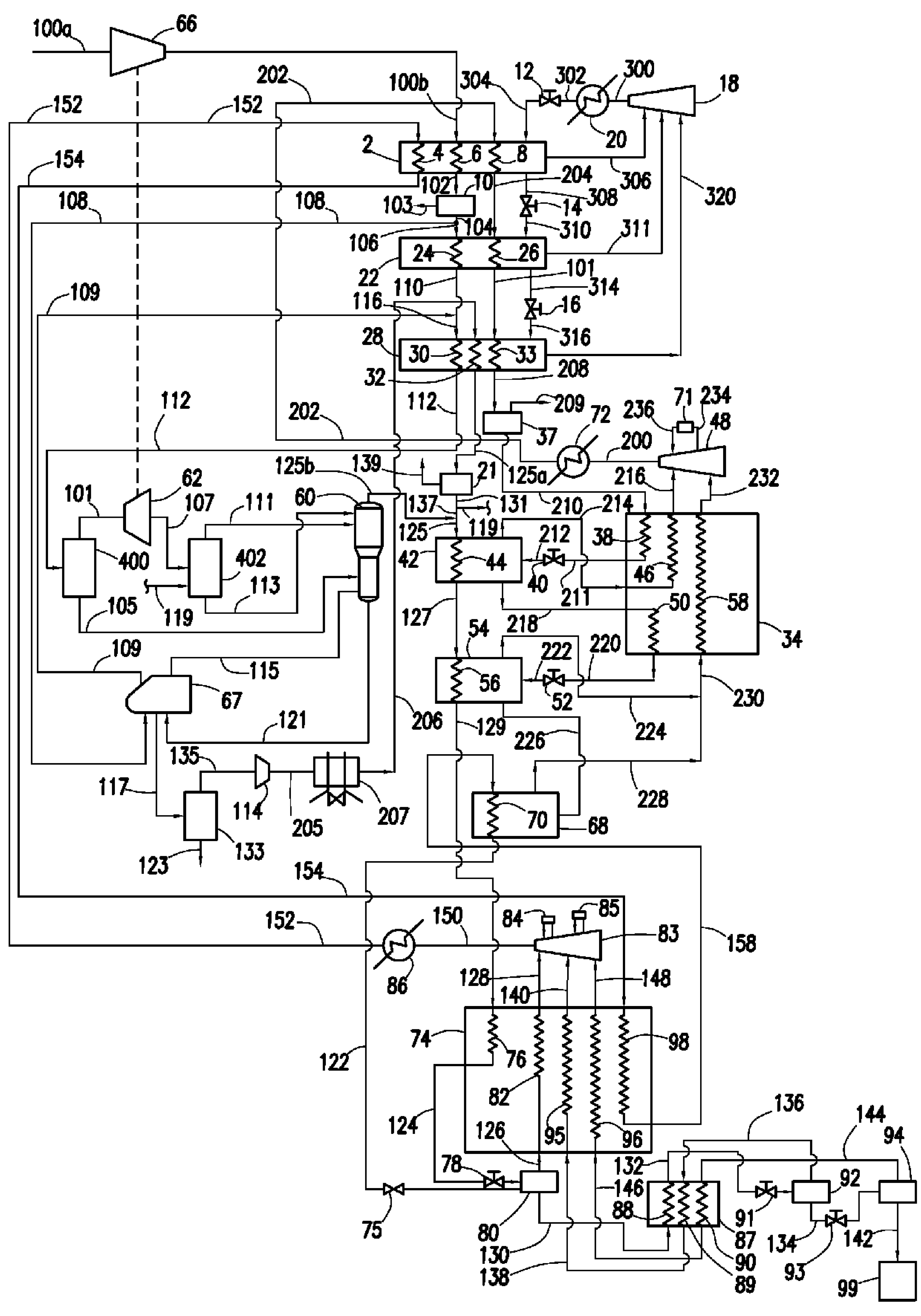
**Publication Classification**

(51) **Int. Cl.**
*F25J 1/00* (2006.01)

(52) **U.S. Cl.**
CPC .................................... *F25J 1/0022* (2013.01)
USPC ............................................................ **62/611**

(57) **ABSTRACT**

This invention relates to a process and apparatus for liquefying natural gas. In another aspect, the invention concerns a liquefied natural gas (LNG) facility employing an ethylene independent heavies recovery system.



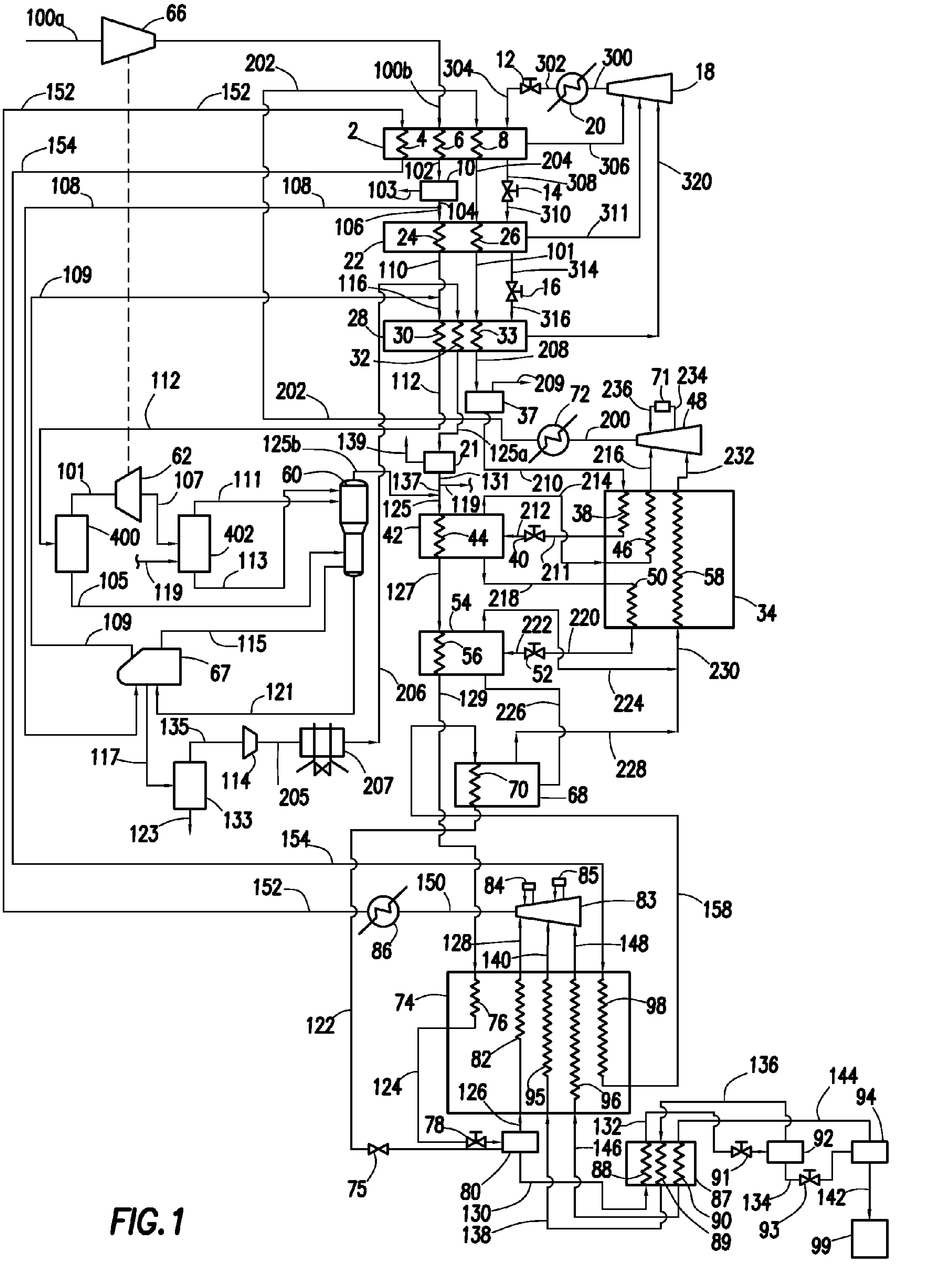


FIG. 1

# LIQUEFIED NATURAL GAS PLANT WITH ETHYLENE INDEPENDENT HEAVIES RECOVERY SYSTEM

## CROSS-REFERENCE TO RELATED APPLICATIONS

**[0001]** This application is a non-provisional application which claims benefit under 35 USC §119(e) to U.S. provisional application Ser. No. 61/522,049 filed Aug. 10, 2011, entitled "Liquefied Natural Gas Plant with Ethylene Independent Heavies Recovery System," which is hereby incorporated by reference.

## FIELD OF THE INVENTION

**[0002]** This invention relates to processes and apparatuses for liquefying natural gas, and more particularly, to a liquefied natural gas (LNG) facility employing an ethylene-independent heavies recovery system.

## BACKGROUND OF THE INVENTION

**[0003]** Natural gas is frequently transported by pipeline from a supply source to a distant market. It is oftentimes desirable to operate the pipeline under a substantially constant and high load factor. However, at times the deliverability or capacity of the pipeline may exceed demand while at other times the demand may exceed the deliverability or capacity of the pipeline. In order to shave off peaks when demand exceeds supply or the valleys when supply exceeds demand, it is desirable to store excess gas in such a manner that it can be delivered during periods when demand exceeds supply. Such practice allows future demand peaks to be met with stored natural gas. One practical means for doing this is to convert natural gas into a liquefied state such as liquefied natural gas ("LNG") via a liquefaction process for storage during periods of low demand and then vaporize the liquefied natural gas as demand requires. Liquefaction of natural gas can be especially useful when a pipeline is either not available or impractical for transporting natural gas from a supply source that is separated by a great distance to a candidate market. Moreover, transport of natural gas by ocean-going vessels is generally not practical because appreciable pressurization is required to significantly reduce the specific volume of the gas. Such pressurization requires the use of more expensive storage containers.

**[0004]** An example of a liquefaction technique is cryogenic liquefaction which can reduce the volume of the natural gas up to about 600-fold. Cryogenic liquefaction can convert natural gas into liquefied natural gas that can be stored and transported at near atmospheric pressures. Cryogenic liquefaction process can involve cooling natural gas down to about −240° F. to about −260° F. while the liquefied natural gas is at near-atmospheric vapor pressure. Natural gas is liquefied by sequentially passing the natural gas at an elevated pressure through a plurality of cooling stages whereupon the natural gas is cooled to successively lower temperatures until liquefaction temperature is reached. Cooling may be accomplished by indirect heat exchange with one or more refrigerants such as propane, propylene, ethane, ethylene, methane, nitrogen, carbon dioxide, or combination of the preceding refrigerants (i.e., mixed refrigerant systems). Some liquefaction techniques employ an open methane cycle for the final refrigeration cycle where a pressurized LNG-bearing stream is flashed. The flash vapors (i.e., the flash gas stream(s)) are subsequently used as cooling agents, recompressed, cooled, combined with processed natural gas feed stream. The combined stream may then be liquefied to produce a pressurized LNG-bearing stream.

**[0005]** One technical challenge that can arise during liquefaction of natural gas is the removal of heavy hydrocarbons. While natural gas is primarily comprised of methane, it may also contain heavy hydrocarbon components. These heavy hydrocarbon components should be removed from the natural gas prior to liquefaction since heavy hydrocarbon components can freeze and/or foul downstream heat exchangers. To avoid these potential issues, LNG facilities can include one or more heavies removal columns for removing heavy hydrocarbon components. However, conventional heavies removal columns often require operation within very narrow ranges of temperature, pressure, and feed composition in order to efficiently remove heavy hydrocarbon components. In some cases, a variation of a few degrees in feed temperature of a conventional heavies removal column can cause all or most of the fluid in the column to turn to liquid, which can result in major process upsets. Moreover, incorporation of heavies removal columns in a liquefaction system can increase power requirements of subsequent refrigeration systems (e.g., ethylene refrigeration system). In some cases, these power requirements can substantially limit operation of a liquefaction system. Thus, a need exists for a process and an apparatus employing a heavies removal column that can reduce the power requirements of subsequent refrigeration systems.

## SUMMARY OF THE INVENTION

**[0006]** In an embodiment of the present invention, a method for liquefaction of natural gas includes: (a) cooling a portion of a natural gas feed stream to produce a cooled natural gas feed stream; (b) combining the cooled natural gas feed stream with a compressed reflux stream to form a combined natural gas stream; (c) separating the combined natural gas stream into a first lights stream and a first heavies stream; (d) expanding the first lights stream to form an expanded first lights stream; (e) introducing at least a portion of the first heavies stream and at least a portion of the expanded first lights stream into a heavies removal column to form a heavies-depleted stream and a heavies-rich stream; (f) separating at least a portion of the heavies-rich stream into a reflux stream and a heavier stream; and (g) compressing the reflux stream into a compressed reflux stream.

**[0007]** In another embodiment of the present invention, a method for liquefaction of natural gas, includes: (a) cooling a portion of a natural gas feed stream via indirect heat exchange with a first refrigerant to form a cooled natural gas feed stream; (b) separating the cooled natural gas feed stream into a first lights stream and a first heavies stream; (c) expanding the first lights stream into an expanded first lights stream; (d) separating the expanded first lights stream into a second lights stream and a second heavies stream; (e) introducing at least a portion of the first heavies stream, at least a portion of the second lights stream and at least a portion of the second heavies stream into a heavies removal column to form a heavies-depleted stream and a heavies-rich stream; (f) cooling at least a portion of the of the heavies depleted stream via indirect heat exchange with a second refrigerant; (g) separating at least a portion of the heavies-rich stream into a reflux stream and a heavier stream; and (h) compressing the reflux stream into a compressed reflux stream.

**[0008]** In a further embodiment of the present invention, an apparatus for liquefaction of natural gas includes: (a) a first heat exchanger in a first refrigeration cycle for cooling a portion of the natural gas stream via indirect heat exchanger with a first refrigerant; (b) a first separator for separating the first cooled natural gas stream into a first lights stream and a first heavies stream; (c) a first expander for expanding the first lights stream into an expanded first lights stream; (d) a heavies removal column positioned downstream of the first heat exchanger, wherein the heavies removal column separates the expanded first lights stream, the first heavies stream and a second cooled liquid stream into a first heavies-depleted stream and a first heavies-rich stream; (e) a separation vessel for separating the first heated liquid stream into a second heavies-depleted stream and a second heavies-rich stream; (f) a second compressor for compressing the second heavies-depleted stream into a compressed second heavies-depleted stream; and (g) a second heat exchanger in the first refrigeration cycle for cooling a combined stream via indirect heat exchange with the compressed second heavies-depleted stream.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0009]** The invention, together with further advantages thereof, may best be understood by reference to the following description taken in conjunction with the accompanying drawing in which:

**[0010]** FIG. **1** is a simplified flow diagram of a cascaded refrigeration process for LNG production in accordance with an embodiment of the present disclosure.

## DETAILED DESCRIPTION OF THE INVENTION

**[0011]** Reference will now be made in detail to embodiments of the present invention, one or more examples of which are illustrated in the accompanying drawing. Each example is provided by way of explanation of the invention, not as a limitation of the invention. It will be apparent to those skilled in the art that various modifications and variations can be made in the present invention without departing from the scope or spirit of the invention. For instance, features illustrated or described as part of one embodiment can be used on another embodiment to yield a still further embodiment. Thus, it is intended that the present invention cover such modifications and variations that come within the scope of the appended claims and their equivalents.

**[0012]** A cascaded refrigeration system uses one or more refrigerants to transfer heat energy from a natural gas stream to the refrigerant(s) and ultimately release the heat energy to its environment. This refrigeration system may be thought of as a heat pump that removes heat energy from the natural gas stream as the stream is progressively cooled to lower and lower temperatures. The design of a cascaded refrigeration system and process often focuses on the tradeoffs between thermodynamic efficiencies and capital costs. Thermodynamically, a heat transfer process between a cool object and a warm object becomes increasingly irreversible as the temperature gradient between the two objects increases. Conversely, thermodynamic irreversibility is reduced as the temperature gradient decreases. Tradeoffs become important considerations because, among other things, reducing the temperature gradient to a thermodynamically efficient level may require significant increases in heat transfer area, major modifications to various process equipment used in a refrigeration system, and proper adjustment of flow rates through the refrigeration system. In particular, proper adjustment of flow rates may affect both flow rates and temperatures (e.g., approach and outlet) in order to obtain desired heating/cooling duty.

**[0013]** As used herein, the term "open-cycle cascaded refrigeration process" refers to a cascaded refrigeration process comprising one open refrigeration cycle and at least one closed refrigeration cycle in which the boiling point of the refrigerant/cooling agent employed in the open cycle is lower than the boiling point of the refrigerating agent employed in the closed cycle. In this process, a portion of the cooling duty used to condense the compressed open-cycle refrigerant/cooling agent may be provided by one or more of the closed cycles. As used herein, a natural gas stream is any stream principally comprised of methane which originates in major portion from a natural gas feed stream, such feed stream containing, for example, at least 85 mole percent methane, with the remaining balance include components such as, but not limited to, ethane, higher hydrocarbons, nitrogen, and carbon dioxide. Other minor contaminants may include, but are not limited to, mercury, hydrogen sulfide, and mercaptan.

**[0014]** According to one or more embodiments of the present invention, a predominately methane stream is employed as the refrigerant/cooling agent in the open cycle. This predominantly methane stream can originate from processed natural gas feed stream and can include compressed open methane cycle gas streams. As used herein, the terms "predominantly", "primarily", "principally", and "in major portion", when used to describe the presence of a particular component of a fluid stream, shall mean that the fluid stream comprises at least **50** mole percent of the stated component. For example, a "predominantly" methane stream, a "primarily" methane stream, a stream "principally" comprised of methane, or a stream comprised "in major portion" of methane each denote a stream comprising at least 50 mole percent methane.

**[0015]** One efficient and effective method of liquefying natural gas involves utilizing an optimized cascade-type operation in conjunction with expansion-type cooling. Such a liquefaction method involves cascade-type cooling of a natural gas stream at elevated pressures (e.g., about 650 psia) by sequentially cooling the natural gas stream via passage through, for example, a multistage propane cycle, a multistage ethane or ethylene cycle, and an open-end methane cycle that utilizes a portion of the feed gas as a source of methane. The method may also include a multistage expansion cycle to further cool and reduce the pressure of the natural gas stream to near-atmospheric pressure. During cooling cycles, the refrigerant with the highest boiling point is utilized first, followed by utilization of refrigerant with next highest boiling point and so forth.

**[0016]** In general, the liquefaction process (i.e., LNG process) may employ one or more refrigerants to extract heat from the natural gas, which is then subsequently rejected into the environment. In some embodiments, the LNG process employs a cascade-type refrigeration process that uses a plurality of multi-stage cooling cycles, each cycle employing a different refrigerant composition, to sequentially cool the natural gas stream to lower and lower temperatures. In other embodiments, the LNG process may utilize mixed refrigerant (s) or refrigerant mixtures to cool the natural gas stream.

**[0017]** Various pre-treatment steps can remove undesirable components from natural gas feed streams. Such undesirable components may include, but are not limited to, acid gases, mercaptan, mercury, moisture, and the like. In some embodiments, the composition of the natural gas feed stream may vary significantly. These pre-treatment steps may be separate steps located either upstream of the cooling cycles or located downstream of one of the early stages of cooling in the initial cycle. As used herein, the terms "upstream" and "downstream" describe the relative positions of various components of a natural gas liquefaction plant along the flow path of natural gas through the plant. In particular, acid gases and to a lesser extent mercaptan can be removed by a chemical reaction process employing an aqueous amine-bearing solution. This treatment step is generally performed upstream of the cooling stages in the initial cycle. A major portion of the water can be removed as a liquid by a two-phase gas-liquid separation that follows gas compression and cooling upstream of the initial cooling cycle and also downstream of the first cooling stage in the initial cooling cycle. Mercury can be removed by mercury sorbent beds. Residual amounts of water and acid gases can be removed by the use of properly selected sorbent beds such as regenerable molecular sieves.

**[0018]** The pre-treated natural gas feed stream may be delivered to the liquefaction system at an elevated pressure or may be compressed to an elevated pressure. In some embodiments, the pressure is greater than about 500 psia or preferably between about 500 psia to about 3000 psia. In some embodiments, about the pressure is between about 500 psia to about 1000 psia or preferably between about 600 psia to about 800 psia. The feed stream temperature is typically near ambient to slightly above ambient. In some embodiments, the temperature may be between about 60° F. to about 150° F. As previously noted, the natural gas feed stream may be cooled by an LNG process involving a plurality of multistage cycles, each cycle containing a different refrigerant. The overall cooling efficiency for a cycle typically improves as the number of stages increases. However, this increase in efficiency is often counter-balanced by a corresponding increase in net capital cost from, for example, an increase in complexity of the LNG system.

**[0019]** In some embodiments, the feed gas is passed through a number of refrigeration cycles, each cycle comprising a number of stages (at least two, preferably two to four, and more preferably two or three). The first closed refrigeration cycle utilizes a first refrigerant with a relatively high boiling point. Such a refrigerant may include a hydrocarbon such as, but not limited to, propane, propylene, and mixtures thereof. In some embodiments, a hydrocarbon is the major portion of the refrigerant. For example, the refrigerant may include at least about 75 mole percent propane, at least 90 mole percent propane, or essentially propane.

**[0020]** After the first refrigeration stage, the resulting processed feed gas flows through a number of stages (at least two, preferably two to four, and more preferably two or three) in a second closed refrigeration cycle that includes a refrigerant with an intermediate boiling point. Suitable examples of the second refrigerant may include, but are not limited to, ethane, ethylene, and mixtures thereof. In some embodiments, the second refrigerant includes at least about 75 mole percent ethylene, at least 90 mole percent ethylene, or essentially ethylene. Each cooling stage of the refrigeration cycle may include a separate cooling zone. As previously noted, the processed natural gas feed stream may be combined with one or more recycle streams (i.e., compressed open methane cycle gas streams) at various locations in the second refrigeration cycle to produce a liquefaction stream. In the last stage of the second cooling cycle, the liquefaction stream is condensed (i.e., liquefied) in major portion, preferably in its entirety, to produce a pressurized LNG-bearing stream. Generally, the process pressure at this location is only slightly lower than the pressure of the pre-treated feed gas in the first stage of the first refrigeration cycle.

**[0021]** It may desirable for the natural gas feed stream to include certain levels of $C_2+$ (i.e., hydrocarbons containing at least two carbons) components such that $C_2+$ rich liquid will form in one or more of the cooling stages. This $C_2+$ rich liquid may be removed via gas-liquid separation means (e.g., gas-liquid separators). Generally, sequential cooling of the natural gas in each stage is controlled so as to remove as much of the $C_2+$ and higher molecular weight hydrocarbons as possible from the gas to produce a gas stream predominating in methane and a liquid stream containing significant amounts of ethane and heavier components.

**[0022]** In some embodiments, a number of gas/liquid separation means can be located at strategic locations downstream of the cooling zones for removal of liquids streams rich in $C_2+$ components. The exact locations and number of gas/liquid separation means will be dependant on a number of operating parameters. Examples of such parameters may include, but are not limited to, $C_2+$ composition of the natural gas feed stream, desired BTU content of the LNG product, value of the $C_2+$ components for other applications, and other factors routinely considered by those skilled in the art of LNG plant and gas plant operation. The $C_2+$ hydrocarbon stream(s) may be demethanized via a single stage flash or a fractionation column to produce a methane-rich stream. In the former case, the resulting methane-rich stream can be repressurized and recycled or used as fuel gas. In the latter case, the resulting methane-rich stream can be directly returned at pressure (i.e., not requiring additional compression to be combined with the liquefaction process) to the liquefaction process. The $C_2+$ hydrocarbon stream(s) or the demethanized $C_2+$ hydrocarbon stream may be used as fuel. In some embodiments, the streams may be further processed, such as by fractionation in one or more fractionation zones to produce individual streams rich in specific chemical constituents (e.g., $C_2$, $C_3$, $C_4$ and $C_5+$ hydrocarbons).

**[0023]** In one or more embodiments, the pressurized LNG-bearing stream undergoes further cooling by a third refrigeration cycle ("open methane cycle") in a main methane economizer containing flash gases (i.e., flash gas streams) generated from this third cycle and by sequential expansion of the pressurized LNG-bearing stream to near atmospheric pressure. The flash gases used as a refrigerant ("third refrigerant") in the third refrigeration cycle may include, but are not limited to, methane. In some embodiments, the third refrigerant comprises at least 75 mole percent methane, at least 90 mole percent methane, or essentially methane. During expansion of the pressurized LNG-bearing stream to near atmospheric pressure, the pressurized LNG-bearing stream is cooled via at least one, preferably two to four, and more preferably three expansions in which each expansion employs an expander as a means of reducing pressure. Suitable expanders may include, for example, Joule-Thomson expansion valves, hydraulic expanders, and the like. The expansion may be followed by a separation of the gas-liquid product using a separator. When a hydraulic expander is employed and properly operated, some of the benefits include greater efficiencies associated with the recovery of power, greater reduction in stream temperature, and production of less vapor during the flash expansion step. These benefits can off-set or exceed the higher capital and operating costs associated with the expander. In some embodiments, additional cooling of the pressurized LNG-bearing stream prior to flashing is made possible by first flashing a portion of this stream via one or more hydraulic expanders and then via indirect heat exchange means employing the flash gas stream to cool the remaining portion of the pressurized LNG-bearing stream prior to flashing. The warmed flash gas stream is then recycled via return to an appropriate location, based on temperature and pressure considerations, in the open methane cycle where it can be recompressed.

**[0024]** The liquefaction process described herein may use one of several types of cooling such as, but not limited to, indirect heat exchange, vaporization, and expansion or pressure reduction. As used herein, the term "indirect heat exchange" refers to a process in which a refrigerant cools a substance without making physical contact with the substance. Specific examples of indirect heat exchange means include, but are not limited to, a shell-and-tube heat exchanger, a core-in-kettle heat exchanger, and a brazed aluminum plate-fin heat exchanger. The physical state of refrigerant and substance to be cooled can vary depending on the demands of the liquefaction system and the type of heat exchanger chosen. For example, a shell-and-tube heat exchanger may be utilized where the refrigerant is in a liquid state and the substance is in a liquid or gaseous state. A shell-and-tube heat exchanger may also be utilized when either the refrigerant or substance undergoes a phase change and process conditions do not favor the use of other exchangers such as a core-in-kettle heat exchanger. Aluminum and aluminum alloys are often used as materials for the core of heat exchangers but may not be suitable for use under certain designated process conditions. For example, a plate-fin heat exchanger may be utilized where the refrigerant is in a gaseous state and the substance is in a liquid or gaseous state. Finally, a core-in-kettle heat exchanger may be utilized where the substance is liquid or gas and the refrigerant undergoes a phase change from a liquid state to a gaseous state during the heat exchange. Vaporization cooling refers to the cooling of a substance by the evaporation or vaporization of a portion of the substance with the system maintained at a constant pressure. During vaporization, a portion of the evaporated substance absorbs heat from the portion of the substance that remains in a liquid state and consequently, the liquid portion is cooled. Finally, expansion or pressure reduction cooling refers to cooling that occurs when the pressure of a gas, liquid or a two-phase system is lowered by passing through a pressure reduction means. In some embodiments, the expansion means may be a Joule-Thomson expansion valve or a hydraulic/gas expander. Because expanders recover work energy from the expansion process, lower process stream temperatures are possible upon expansion.

**[0025]** Referring to FIG. **1**, a natural gas feed stream is fed into inlet compressor **66** downstream of a dehydration unit and a mercury removal unit via conduit **100***a* to produce a compressed natural gas feed stream. The compressed natural gas feed stream is then fed into a high-stage propane chiller **2** via conduit **100***b* to produce a cooled natural gas feed stream. A number of other conduits (e.g., **152**, **202**, **304**) also lead into the high-stage propane chiller **2**. In the illustrated embodiment, gaseous methane refrigerant that is part of the closed loop propane system is introduced into the high-stage propane chiller **2** via conduit **152** while compressed ethylene refrigerant is introduced via conduit **202**. Streams **100***b*, **152**, and **202** are cooled by indirect heat exchange means **6**, **4**, and **8** respectively to produce cooled gas streams that flow through conduits **102**, **154**, and **204** respectively. The indirect heat exchange occurs between the aforementioned streams and propane that has been processed as follows.

**[0026]** Gaseous propane that is part of the closed loop propane system may be compressed in a multistage (e.g., a three-stage) compressor **18** driven by a gas turbine driver (not illustrated). Each stage of the compressor may be separate units, mechanically coupled to one another to be driven by a single driver or combination of drivers. The resulting compressed propane may be passed through conduit **300** to a cooler **20** where it is cooled and liquefied. While pressure and temperature of the liquefied propane refrigerant prior to flashing can vary, representative values may be about 100° F. and about 190 psia. The stream from cooler **20** is passed through conduit **302** to a pressure reduction means, illustrated as expansion valve **12**. Here the pressure of the liquefied propane is reduced, thereby evaporating or flashing a portion of the liquefied propane. The resulting two-phase product then flows through conduit **304** into a high-stage propane chiller **2**.

**[0027]** After the indirect heat exchange has taken place, the propane gas can exit the high-stage propane chiller **2** and return to compressor **18** via conduit **306**. This propane gas is fed into the high-stage inlet port of compressor **18**. The remaining liquid propane from the indirect heat exchange can exit the high-stage propane chiller **2** via conduit **308**. The pressure of the liquid propane may be further reduced by passage through a pressure reduction means, illustrated as expansion valve **14**, whereupon at least a portion of the liquefied propane is flashed. The resulting two-phase propane stream is then fed via conduit **310** into an intermediate-stage propane chiller **22** where it can serve as a coolant.

**[0028]** The cooled natural gas feed stream described earlier can exit the chiller high-stage **2** through conduit **102** into separation equipment **10** that can separate a stream into gas and liquid phases. The liquid phase can be rich in $C_3$+ components and is removed via conduit **103**. The gaseous phase exits the separation equipment **10** via conduit **104** that splits into two separate conduits (**106** and **108**). The stream in conduit **106** continues into the intermediate-stage propane chiller **22**. Compressed ethylene refrigerant stream is also introduced into the intermediate-stage propane chiller **22** (via conduit **204**). The streams that flows through conduits **106** and **204** are cooled via indirect heat exchange means **24** and **26** respectively to produce cooled gas streams in conduits **110** and **101**. Once the propane refrigerant has cooled the streams, at least a portion of the propane evaporates. This evaporated portion is separated and passed through conduit **311** into the intermediate-stage inlet of compressor **18**. The remaining liquid portion of the propane refrigerant from the intermediate-stage propane chiller **22** is removed via conduit **314** and flashed across a pressure reduction means, illustrated as expansion valve **16**. The flashed propane is then fed into a low-stage propane chiller/condenser **28** via conduit **316**.

**[0029]** In the embodiment illustrated in FIG. **1**, the natural gas stream flows from intermediate-stage propane chiller **22** via conduit **110** and combines with a chilled natural gas stream from conduit **109** to form a combined natural gas stream. A portion of the combined natural gas stream then flows into the low-stage propane chiller **28** via conduit **116**. Also flowing into the low-stage propane chiller **28** is a portion of a second heavies-depleted stream via conduit **206** and the ethylene refrigerant stream via conduit **101**. The combined natural gas stream, the second heavies-depleted stream, and the ethylene refrigerant stream are cooled by indirect heat exchange means **30**, **32**, and **33** respectively to produce cooled gas streams **112**, **125***a*, and **208** respectively. The indirect heat exchange means produce vaporized propane which is removed from low-stage propane chiller **28** and returned to the low-stage inlet of compressor **18** via conduit **320**. In some embodiments, the propane refrigeration cycle utilizes a high-stage chiller and a low-stage chiller.

**[0030]** Still referring to FIG. **1**, a portion of the cooled natural gas stream exiting the low-stage propane chiller **28** is introduced into separator **400** via conduit **112**. The separator **400** separates the cooled natural gas stream into a first heavies stream and a first lights stream. The separator **400** typically operates at high pressures. The first heavies stream from separator **400** is sent to the middle of the heavies removal column **60** via conduit **105**. The first lights stream from separator **400** is fed into expander **62** (which drives the inlet compressor **66**). Upon expansion, the first lights stream is introduced to separator **402** via conduit **107**. A portion of the stream that exits surge drum **21** may also be introduced into separator **402** via conduit **119**. The streams in separator **402** produce a second lights stream and a second heavies stream. Typically, separator **402** operates at relatively low pressures. In some embodiments, separator **400** operates at a higher pressure than separator **402**. The second lights stream exiting separator **402** is introduced to the heavies removal column **60** via conduit **111**. Likewise, the second heavies stream exiting separator **402** is introduced to the heavies removal column **60** via conduit **113**. Locating heavies removal column **60** immediately downstream of low-stage propane chiller **28** widens the acceptable operating parameters of heavies removal column **60** compared to known systems. The heavies removal column **60** produces a heavies-depleted vapor stream that exits column **60** via conduit **125***b* and a heavies-rich liquid stream that exits column **60** via conduit **121**.

**[0031]** The heavies-rich liquid stream exiting the heavies removal column **60** via conduit **121** is fed into reboiler **67**. Heat exchange takes place in reboiler **67** between the heavies rich liquid stream introduced via conduit **121** and at least a portion of the stream exiting separation vessel **10** via conduit **108**. The heavies-rich stream exiting the heavies removal column **60** via conduit **121** serves to cool down the portion of the natural gas feed stream from conduit **108** in reboiler **67**. The resulting chilled natural feed gas stream from conduit **109** is combined with a portion of the cooled natural gas stream in conduit **110** to produce a combined natural gas stream in conduit **116**. Stream in conduit **115** is a hot light vapor stream that exits from the reboiler **67** and acts as a stripping gas in the heavies removal column **60**. Stream in conduit **117** is the heavy liquid product from the reboiler **67** which is sent to column **133** (a depropanizer) for further processing and stabilization. Stream in conduit **117** exiting reboiler **67** is introduced to vessel **133** for flashing or fractionating. A second heavies-rich stream is produced via conduit **123** and a second heavies-depleted vapor stream is produced via conduit **135**. The second heavies-depleted stream is fed into compressor **114** so that it can be chilled and condensed to form the reflux for the heavies removal column. The compressed second heavies-depleted stream flows to cooler **207** via conduit **205**. This chilled second heavies-depleted stream is fed to low-stage propane chiller **28** via conduit **206** where it is condensed via indirect heat exchange means **32**, removed via conduit **125***a* and fed to surge drum **21**. The liquid is removed from surge drum **21** via conduit **131**. A portion of the stream exiting surge drum **21** in conduit **131** is introduced into separator **402** via conduit **119**. The remaining portion of the stream exiting surge drum **21** in conduit **131** is combined with the heavies-depleted vapor stream exiting heavies removal column **60** in conduit **125***b* to form combined stream **125**.

**[0032]** Ethylene refrigerant exits low-stage propane chiller **28** via conduit **208** and is preferably fed to a separation vessel **37** wherein light components are removed via conduit **209** and condensed ethylene is removed via conduit **210**. The ethylene refrigerant at this location in the process is generally at a temperature of about −24° F. and a pressure of about 285 psia. The liquid stream exiting surge drum **37** in conduit **210** then flows into an ethylene economizer **34** where it is cooled via indirect heat exchange means **38**, removed via conduit **211**, and passed through a pressure reduction means, illustrated as an expansion valve **40**, whereupon the refrigerant is flashed to a specified temperature and pressure, and fed to high-stage ethylene chiller **42** via conduit **212**. Vapor is removed from chiller **42** via conduit **214** and routed to ethylene economizer **34** where the vapor functions as a coolant via indirect heat exchange means **46**. The ethylene vapor is then removed from ethylene economizer **34** via conduit **216** and fed to the high-stage inlet of ethylene compressor **48**. The ethylene refrigerant that is not vaporized in high-stage ethylene chiller **42** is removed via conduit **218** and returned to ethylene economizer **34** for further cooling via indirect heat exchange means **50**, removed from ethylene economizer via conduit **220**, and flashed in a pressure reduction means, illustrated as expansion valve **52**, whereupon the resulting two-phase product is introduced into an intermediate-stage ethylene chiller **54** via conduit **222**.

**[0033]** The heavies-depleted vapor stream exiting heavies removal column **60** via conduit **125***b* is combined with at least a portion of the cooled stream exiting low stage chiller **28** via conduit **137** to form combined stream **125**. The combined stream undergoes further cooling in high-stage ethylene chiller **42** via indirect heat exchange means **44**. After cooling the methane-rich stream is removed from high-stage ethylene chiller **42** via conduit **127**. This stream is then condensed in part via cooling provided by indirect heat exchange means **56** in low-stage ethylene chiller **54**, thereby producing a two-phase stream that is directed to a main methane economizer **74** via conduit **129**, where the stream is further cooled by indirect heat exchange means/heat exchanger pass **76**.

**[0034]** As previously noted, the gas in conduit **154** is fed to main methane economizer **74** where the stream is cooled via indirect heat exchange means **98**. The resulting cooled compressed methane recycle or refrigerant stream in conduit **158** is further cooled in the low-stage ethylene chiller **68**. In low-stage ethylene chiller **68**, this stream is cooled and condensed via indirect heat exchange means **70** with the liquid effluent from valve **52** that is routed to low-stage ethylene chiller **68** via conduit **226**. The condensed methane-rich product from low-stage condenser **68** is produced via conduit **122**. The vapor from low-stage ethylene chiller **54**, withdrawn via conduit **224**, and the stream from low-stage ethylene chiller **68**, withdrawn via conduit **228**, are combined and routed via conduit **230** to ethylene economizer **34** wherein the vapors function as a coolant via indirect heat exchange means **58**.

The stream is then routed via conduit **232** from ethylene economizer **34** to the low-stage inlet of ethylene compressor **48**.

**[0035]** As shown in FIG. **1**, the compressor effluent from vapor introduced via the low-stage side of ethylene compressor **48** is removed via conduit **234**, cooled via inter-stage cooler **71**, and returned to compressor **48** via conduit **236** for injection with the high-stage stream present in conduit **216**. Preferably, the two-stages are a single module although they may each be a separate module where the modules are mechanically coupled to a common driver. The compressed ethylene product from compressor **48** is routed to a downstream cooler **72** via conduit **200**. The product from cooler **72** flows via conduit **202** and is introduced, as previously discussed, to high-stage propane chiller **2**.

**[0036]** It may be preferable that the main methane economizer **74** includes a plurality of heat exchanger passes that provide for the indirect exchange of heat between various predominantly methane streams in the economizer **74**. Preferably, methane economizer **74** comprises one or more plate-fin heat exchangers. The cooled stream from heat exchanger pass **76** exits methane economizer **74** via conduit **124**. The pressure of the stream in conduit **124** is then reduced by a pressure reduction means, illustrated as expansion valve **78** that evaporates or flashes a portion of the liquid stream thereby generating a two-phase stream. The pressure of the stream exiting low-stage ethylene chiller **68** via conduit **122** is reduced by a pressure reduction means, illustrated as expansion valve **75**, which evaporates or flashes a portion of the liquid stream thereby generating a two-phase stream. The two-phase stream from expansion valve **78** then passes through high-stage methane flash drum **80** along with the two-phase stream from expansion valve **75** where they are separated into a flash gas stream discharged through conduit **126** and a liquid phase stream (i.e., pressurized LNG-bearing stream) discharged through conduit **130**. The flash gas stream is then transferred to main methane economizer **74** via conduit **126** where the stream functions as a coolant in heat exchanger pass **82** and aids in the cooling of the stream in heat exchanger passes **76** and **98**. Thus, the predominantly methane stream in heat exchanger pass **82** is warmed, at least in part, by indirect heat exchange with the predominantly methane stream in heat exchanger pass **76**. The warmed stream exits heat exchanger pass **82** and methane economizer **74** via conduit **128**. It is preferred for the temperature of the warmed predominantly methane stream exiting heat exchanger pass **82** via conduit **128** to be at least about 10° F. greater than the temperature of the stream in conduit **124**, and more preferably at least about 25° F. greater than the temperature of the stream in conduit **124**. The temperature of the stream exiting heat exchanger pass **82** via conduit **128** is preferably warmer than about −50° F., more preferably warmer than about 0° F., still more preferably warmer than about 25° F., and most preferably in the range of from about 40° F. to about 100° F.

**[0037]** The liquid-phase stream exiting high-stage flash drum **80** via conduit **130** is passed through a second methane economizer **87** where the liquid is further cooled by downstream flash vapors via indirect heat exchange means **88**. The cooled liquid exits second methane economizer **87** via conduit **132** and is expanded or flashed via pressure reduction means, illustrated as expansion valve **91**, to further reduce the pressure and vaporize a second portion thereof. This two-phase stream is passed to an intermediate-stage methane flash drum **92** where the stream is separated into a gas phase passing through conduit **136** and a liquid phase passing through conduit **134**. The gas phase flows through conduit **136** to second methane economizer **87** where the vapor cools the liquid introduced to economizer **87** via conduit **130** via indirect heat exchanger means **89**. Conduit **138** serves as a flow conduit between indirect heat exchange means **89** in second methane economizer **87** and heat exchanger pass **95** in main methane economizer **74**. The warmed vapor stream from heat exchanger pass **95** exits main methane economizer **74** via conduit **140** and is conducted to the intermediate-stage inlet of methane compressor **83**.

**[0038]** The liquid phase stream exiting intermediate-stage flash drum **92** via conduit **134** is further reduced in pressure by passage through a pressure reduction means, illustrated as an expansion valve **93**. Again, a portion of the liquefied natural gas is evaporated or flashed. The two-phase stream from expansion valve **93** is passed to a final or low-stage flash drum **94**. flash drum **94**, a vapor phase is separated and passes through conduit **144** to the second methane economizer **87**. Here the vapor functions as a coolant via indirect heat exchange means **90**, exits second methane economizer **87** via conduit **146** that is connected to the first methane economizer **74** where the vapor functions as a coolant via heat exchanger pass **96**. The warmed vapor stream from heat exchanger pass **96** exits main methane economizer **74** via conduit **148** and is conducted to the low-stage inlet of compressor **83**.

**[0039]** The liquefied natural gas product from low-stage flash drum **94**, which is at approximately atmospheric pressure, is passed through conduit **142** to a LNG storage tank **99**. In accordance with conventional practice, the liquefied natural gas in storage tank **99** can be transported to a desired location (typically via an ocean-going LNG tanker). The LNG can then be vaporized at an onshore LNG terminal for transport in the gaseous state via conventional natural gas pipelines.

**[0040]** As shown in FIG. **1**, the high, intermediate, and low stages of compressor **83** are combined as single unit. While this may be preferred in some embodiments, each stage may exist as a separate unit, each unit mechanically coupled to each other so that the units may be driven by a single driver. The compressed gas from the low-stage section passes through an inter-stage cooler **85** and is combined with the intermediate pressure gas in conduit **140** prior to the second-stage of compression. The compressed gas from the intermediate stage of compressor **83** is passed through an inter-stage cooler **84** and is combined with the high pressure gas provided via conduit **128** prior to the third-stage of compression. The compressed gas (i.e., compressed open methane cycle gas stream) is discharged from high stage methane compressor through conduit **150**, is cooled in cooler **86**, and is routed to the high pressure propane chiller **2** via conduit **152** as previously discussed. The stream is cooled in chiller **2** via indirect heat exchange means **4** and flows to main methane economizer **74** via conduit **154**. The compressed open methane cycle gas stream from chiller **2** which enters the main methane economizer **74** undergoes cooling in its entirety via flow through indirect heat exchange means **98**. This cooled stream is then removed via conduit **158** and cooled in the low-stage ethylene chiller **68**.

**[0041]** In one or more embodiment of the present invention, the LNG production systems illustrated in FIG. **1** is simulated on a computer using conventional process simulation software. Examples of suitable simulation software include

HYSYS.™. from Hyprotech, Aspen Plus.®. from Aspen Technology, Inc., and PRO/II.®. from Simulation Sciences Inc.

**[0042]** Although the systems and processes described herein have been described in detail, it should be understood that various changes, substitutions, and alterations can be made without departing from the spirit and scope of the invention as defined by the following claims. Those skilled in the art may be able to study the preferred embodiments and identify other ways to practice the invention that are not exactly as described herein. It is the intent of the inventors that variations and equivalents of the invention are within the scope of the claims while the description, abstract and drawings are not to be used to limit the scope of the invention. The invention is specifically intended to be as broad as the claims below and their equivalents.

**1**. A method for liquefaction of natural gas comprising:
- a) cooling a portion of a natural gas feed stream to produce a cooled natural gas feed stream;
- b) combining the cooled natural gas feed stream with a compressed reflux stream to form a combined natural gas stream;
- c) separating the combined natural gas stream into a first lights stream and a first heavies stream;
- d) expanding the first lights stream to form an expanded first lights stream;
- e) introducing at least a portion of the first heavies stream and at least a portion of the expanded first lights stream into a heavies removal column to form a heavies-depleted stream and a heavies-rich stream;
- f) separating at least a portion of the heavies-rich stream into a reflux stream and a heavier stream; and
- g) compressing the reflux stream into a compressed reflux stream.

**2**. The method of claim **1**, wherein (a)-(g) are carried out in a multi-stage cascade-type liquefied natural gas facility.

**3**. The method of claim **1**, wherein a portion of the natural gas feed stream is cooled via indirect heat exchange with a first refrigerant.

**4**. The method of claim **3**, wherein the first refrigerant comprises predominantly propane or predominantly propylene.

**5**. A method for liquefaction of natural gas comprising:
- a) cooling a portion of a natural gas feed stream via indirect heat exchange with a first refrigerant to form a cooled natural gas feed stream;
- b) separating the cooled natural gas feed stream into a first lights stream and a first heavies stream;
- c) expanding the first lights stream to form an expanded first lights stream;
- d) separating the expanded first lights stream into a second lights stream and a second heavies stream;
- e) introducing at least a portion of the first heavies stream, at least a portion of the second lights stream, and at least a portion of the second heavies stream into a heavies removal column to form a heavies-depleted stream and a heavies-rich stream;
- f) cooling at least a portion of the heavies depleted stream via indirect heat exchange with a second refrigerant;
- g) separating at least a portion of the heavies-rich stream into a reflux stream and a heavier stream; and
- h) compressing the reflux stream into a compressed reflux stream.

**6**. The method of claim **1**, wherein (a)-(h) are carried out in a multi-stage cascade-type liquefied natural gas facility.

**7**. The method of claim **5**, wherein the first refrigerant comprises predominately propane or predominantly propylene.

**8**. The method of claim **5**, wherein the second refrigerant comprises predominantly ethane or predominantly ethylene.

**9**. An apparatus for liquefaction of natural gas comprising:
- a) a first heat exchanger in a first refrigeration cycle for cooling a portion of the natural gas stream via indirect heat exchanger with a first refrigerant;
- b) a first separator for separating the first cooled natural gas stream into a first lights stream and a first heavies stream;
- c) a first expander for expanding the first lights stream into an expanded first lights stream;
- d) a heavies removal column positioned downstream of the first heat exchanger, wherein the heavies removal column separates the expanded first lights stream, the first heavies stream and a second cooled liquid stream into a first heavies-depleted stream and a first heavies-rich stream;
- e) a separation vessel for separating the first heated liquid stream into a second heavies-depleted stream and a second heavies-rich stream;
- f) a second compressor for compressing the second heavies-depleted stream into a compressed second heavies-depleted stream; and
- g) a second heat exchanger in the first refrigeration cycle for cooling a combined stream via indirect heat exchange with the compressed second heavies-depleted stream.

**10**. The apparatus of claim **9**, wherein the first refrigerant comprises predominately propane or predominantly propylene.

**11**. The apparatus of claim **9**, wherein the second refrigerant comprises predominately ethane or predominantly ethylene.

**12**. The apparatus of claim **9**, wherein at least one of: the first refrigerant and the second refrigerant comprises predominately propane, predominantly propylene, predominantly ethane, predominantly ethylene, or a mixture thereof.

**13**. The apparatus of claim **9** including at least three refrigerants, wherein each refrigerant comprises a different composition.

* * * * *